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The different effects of regional and local winds on dew formation in the Negev desert

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Abstract: With dew serving as an important water source for various small organisms and plants in deserts, knowledge regarding the spatial distribution of dew (which constitutes an important fraction of the non-rainfall water, NRW) is of prime importance. This is also the case for the Negev dew desert. According to the classical model, local nocturnal katabatic winds that descend down the slopes during the night to the wadi beds are responsible for the accumulation of cold air, subsequently triggering dew formation in the wadis. Nevertheless, NRW measurements that were conducted in a one-order drainage basin in the Negev during the dewy season (late summer and fall) yielded half the amount in the wadi bed in comparison to the hilltop, attributed to the sheltered position of the wadi from the cooling effect of the regional (sea-breeze) winds, which are not considered by the classical model. Hypothesizing that the classical model may however take place at wide wadi where the sea breeze winds are not sheltered, measurements of dew and temperatures were periodically carried out at the beds of a 5 m-wide narrow (NW) and a 200 m-wide (WW) wadi beds and at the hilltop (HT). The findings did not fully support our hypothesis. In comparison to the hilltop, and despite the mutual effect of the katabatic and the sea breeze winds on the wide wadi bed, also the wide wadi exhibited lower amounts of dew than that of the hilltop, with NRW following the pattern HT > WW > NW. The overwhelming effect of the sea-breeze winds was also supported indirectly by periodic NRW and temperature measurements during the winter during which the sea breeze does not commonly take place. Evidence suggests that whereas the classical model takes place during the winter during which the katabatic winds may play a central role in dew formation, the occurrence of the sea breeze (regional wind) during the late summer and fall overshadows the effect of the local katabatic winds. Our findings point to the possibility that the classical model may not adequately predict dew formation in regions subjected to sea-breeze winds.

Keywords: Katabatic winds; Non-rainfall water (NRW); Sea breeze; Surface temperatures.

1 INTRODUCTION

Dew is regarded as an important water source for arid and semiarid regions. It may not only contribute water during the long rainless seasons but also provides nutrients (Kidron and Starinsky, 2012). It may play an important role in the growth and vitality of various organisms, especially in dew deserts, where annual rain amounts are very limited, and dew may sometimes provide a higher input of water than rain (Evenari et al., 1971).

The Negev Desert in Israel is considered as a dew desert. With 33 mm of annual input and ~200 dewy days, dew was found to provide water to plants (Hill et al., 2015), lithic lichens (Lange et al., 1970) and insects (Broza, 1979). Similarly to rain, dew exhibits spatial variability linked to geography (Ashbel, 1949; Kidron and Temina, 2013), topography (Duvdevani, 1957; Kidron et al., 2000; Lloyd, 1961) and lithology (Temina and Kidron, 2015). At a micro scale, dew may be impacted by height above ground (Clus et al., 2009; Kidron et al., 2000), angle (Beysens et al., 2016; Kidron and Temina, 2017) and substrate type (Beysens, 1995; Monteith, 1957; Takenaka et al., 2003). High variability was also found within a single drainage basin. Within a one-order drainage basin in the Negev Highlands, the highest dew amounts were obtained at the north-facing footslope and at the hilltops, while the lowest amounts were obtained at the south-facing midslope and the wadi bed. This was not a trivial finding as it contradicts the classical model of dew accumulation (Kidron, 2000a; Kidron et al., 2000).

The classical model considers the effect of local winds, i.e., katabatic winds. Accordingly, wadi beds are expected to obtain the highest amount of dew within the drainage basin (Geiger, 1966; Oke, 1978). Consequently, near-surface nocturnal cooling results in a descent of the heavy cold air (katabatic winds) from the slopes into the wadi beds. With dew formation taking place once the surface temperature (T_s) reaches the dew point temperature (T_d), i.e., $T_s \leq T_d$, the cold air which results from the local katabatic winds triggers dew formation. Higher dew amounts at the wadi bed are therefore anticipated by the classical model. Nevertheless, this was not the case during extended measurements that took place during the dewy season (late summer and fall) within a drainage basin in the Negev Highlands. Hilltops at the drainage basin yielded twice as much NRW as the amount obtained at the wadi beds, attributed to the cooling effect of the afternoon wind breeze (Kidron, 2000a; Kidron et al., 2000). It was therefore hypothesized that habitats which are exposed to the afternoon sea breeze may experience early and fast cooling rates which may trigger dew formation (Kidron et al., 2016). It was further hypothesized that while dew formation will be delayed at narrow wadis that are sheltered from the cooling effect of the afternoon sea-breeze, and therefore do not comply with the classical model, wide wadis subjected to the cooling effect of the sea-breeze will exhibit higher dew amounts than that of the hilltop and may therefore comply with the classical model.

This hypothesis was partially supported by periodic wind measurements that exhibited substantially higher wind velocities at the wide wadi in comparison to the narrow wadi (Figure 1). However, this hypothesis was not supported by temperature measurements that occasionally showed lower minimum temperatures at the narrow wadi (Kidron, unpub). In analogy to lichen biomass that is principally determined by the *length of time* of the dew rather than the *amount* of dew (Kappen et al., 1979), we hypothesized that rather than being principally controlled by a single value of the minimum temperature (commonly at dawn), the amounts of dew are mainly controlled by the time duration during which $T_s \leq T_d$. For verifying this hypothesis, periodic dew and temperature measurements were conducted. Carried out at a wide and a narrow wadi beds and at an adjacent hilltop, the measurements took place during the fall seasons of 2009, 2012 and 2014.

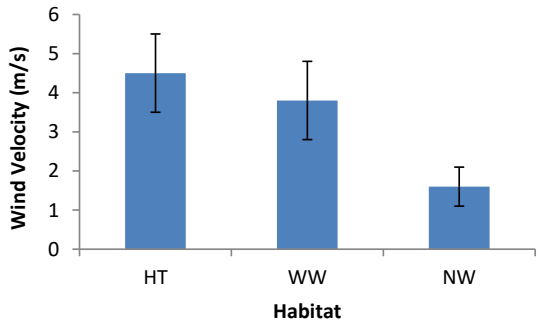

Fig. 1. Periodic measurements of wind during 1988 at the narrow and wide wadis and at the hilltop. Bars represent one SE.

2 METHODOLOGY

2.1 The research site

The research was conducted in a drainage basin next to Kibbutz Sede Boqer (34º23'E, 30º56'N) in the Negev Desert Highlands, at 500–550 m a.m.s.l. (Figure 2a). The research site is located within low limestone hills ~50 m-high. Annual long-term mean precipitation is ~95 mm falling during the winter months, between November and April (Rosenan and Gilad, 1985). The site is characterized by southwesterly winds during the winter, with milder north-westerly winds during the summer. The sea breeze that characterizes the summer and early fall (entering the area during the afternoon and lasting until the early evening hours) carries vapor from the Mediterranean Sea. Dew is common with ~200 d per year and an annual amount of ~33 mm (Evenari et al., 1971), with late summer and fall being especially dewy (Zangvil, 1996). Average daily annual temperature is 17.9 ºC, with 24.7 ºC during the hottest month of July and 9.3 ºC during the coldest month of January (Bitan and Rubin, 1991). Annual potential evaporation is ~2600 mm (Evenari, 1981). Climate classification according to Köppen (1936) is *BWh*, with an aridity index (AI) <0.05, which denotes a hyper-arid zone (FAO, 1977; Spinoni et al., 2015).

Within the hilly limestone bedrocks, scattered cobbles which lie on the loessial soil and are inhabited by chlorolichens (lichens with green algae as photobionts) are common. The site is characterized by 40–60 cm-high shrubs, with 10–30% cover.

2.2 Methods

A pair of 2 m × 2 m plots, 30 m apart, were established at three habitats: at a 100 m-wide wadi (WW), at 470 m a.m.s.l., and 5–7 m-wide narrow wadi (NW) at 480 m a.m.s.l., both

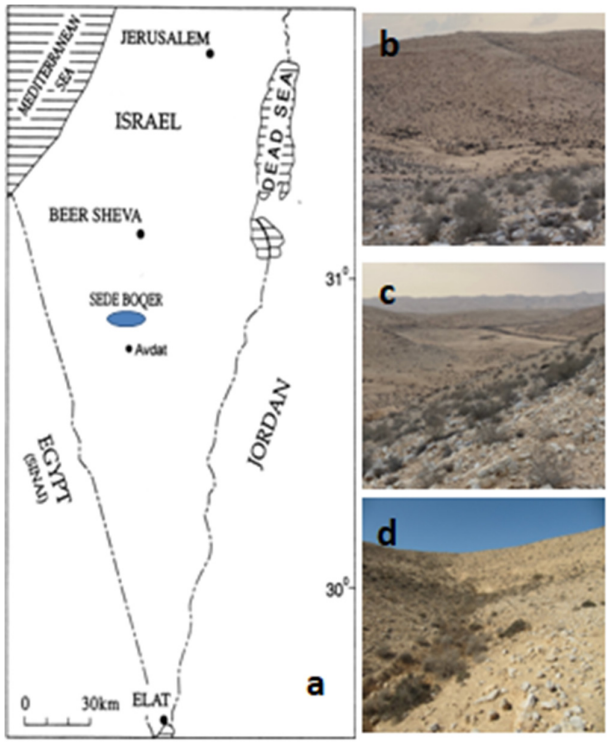

Fig. 2. Location of the research sites (a) and view of HT (b), WW (c) and NW (d).

trending east-west, and at a hilltop (HT), at 540 m a.m.s.l. (Figure 2b, c, d).

Temperatures and dew measurements were periodically carried out at all plots. Dew measurements were carried out using the cloth-plate method (CPM) found to closely reflect the amount of dew that forms on 5–10 cm-high cobbles (Kidron, 2000b). It consists of 6 cm × 6 cm × 0.1 cm cloth (Vileda, Germany) attached to the center of 10 cm × 10 cm × 0.2 cm glass plate overlying 10 cm × 10 cm × 0.5 cm plywood plate. It creates a substrate of 0.7 cm above ground, which may closely reflect the underlying soil/rock (Kidron et al., 2000). The cloths were attached during the afternoon and collected during the early morning of the following day. Each cloth was put into a separate glass flask that was immediately sealed and brought to a nearby lab. The cloths were weighed, oven-dried at 70 °C until reaching a constant weighed, and reweighed. The amount of dew was calculated according to the equation:

$$WC\ (mm) = (WC_{wet} – WC_{dry})/A\rho \times 10 \quad (1)$$

where WC is the amount of water in millimeters, WC_{wet} and WC_{dry} are the wet and dry water contents of the cloths in grams, respectively, A is the surface area in cm^2, and ρ is the density of water (g cm^{-3}) at a given temperature. The values were multiplied by 10 to obtain the WC in millimeters.

Following Kappen et al. (1979), 0.03 mm, which was found to reflect the minimum amount of water for the respiration of chlorolichens (hereafter lichens), was regarded as the minimum amount of non-rainfall water (NRW) relevant for lichen activity. A daily amount ≥ 0.03 mm obtained by the CPM was hitherto considered as a dewy morning.

Temperature sensors attached to the surface of ~10 cm × 10 cm × 5 cm cobbles served to characterize the temperature regime.

We used TMC6-HD thermistors (±0.05 ºC), 3 cm-long and 0.5 cm-diameter (Onset Computer Corporation, MA, USA) that were attached to a cobble in each plot. To avoid biased data due to direct radiation, the sensors were sheltered from direct radiation by 4 cm × 1 cm × 0.5 cm polyurethane. The sensors were connected to U-12 Hobo (Onset Computer Corporation, MA, USA) data loggers, and the temperatures were registered and stored in 20 min-intervals.

One-way ANOVA was executed in order to assess whether the different stations yielded significantly different temperatures and dew amounts. Once significant, paired *t*-tests were executed. Values were considered significant at $P < 0.05$.

3 RESULTS

A total of 25 days of dewy mornings and 10 days of foggy mornings were measured. All habitats exhibited significant differences among them, as verified by the ANOVA test. As shown during 12 days of concomitant measurements (Figure 3a), and the average amounts for all measured days (Figure 3b), the amounts obtained generally followed the trend: HT > WW > NW. This trend was consistent whether during dewy or foggy mornings.

Concomitant and average daily temperatures as measured during 16 days at HT, WW and NW are shown in Figure 4. Expectedly, NW exhibited the highest maximum temperatures followed by WW and then by HT. As for the minimum temperatures, the values followed the pattern: WW < HT ≈ NW. A close examination of the temperature distribution showed however that while NW exhibited relatively high temperatures during the entire night, HT exhibited the lowest nocturnal temperatures until 02:00 to 03:00, with WW exhibiting the lowest temperatures thereafter. HT just exhibited the lowest temperatures for most of the nighttime hours.

4 DISCUSSION

As far as dew is concerned, its amount is dictated by the amount of vapor and the nighttime temperatures, but also on the wind regime. In addition to the impact of wind on rain (Iserloh et al., 2013), evaporation (Kidron and Zohar, 2010), dust emission, erosion and weathering (Jia et al., 2008; Lee, 1987; Riksen and Goossens, 2007; Rodriguez-Navarro et al., 1999), and hence on the biota (Aylor, 1990; Tanaka et al., 1998), wind plays also a central role in dew formation. Both low (< 0.5 m s^{-1}) and high (> 4.5 m s^{-1}) nocturnal winds impede dew (Monteith, 1957; Muselli et al., 2009; Zhuang and Zhao, 2014). Thus, low-velocity nocturnal winds may not be able to replenish the vapor required for continuous dew formation, while turbulence following high wind velocity will impede the inversion conditions required for vapor condensation (Beysens, 2018; Oke, 1978). High wind velocities during the early morning may also result in lower dew amounts, either by impeding early morning condensation, or due to increased evaporation (Kidron, 2000a). On the other hand, by surface cooling and the subsequent drop in surface temperatures, high-velocity winds during the late afternoon may trigger dewfall.

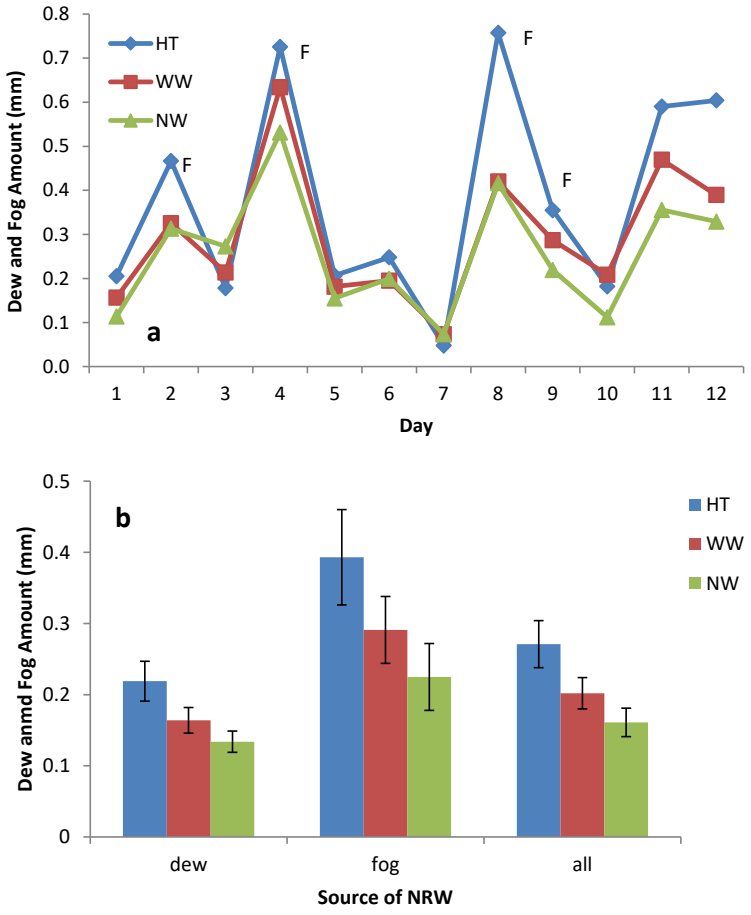

Fig. 3. Concomitant dew and fog measurements (a) and average dew and fog amounts (b) as obtained at the three habitats. Bars represent one SE.

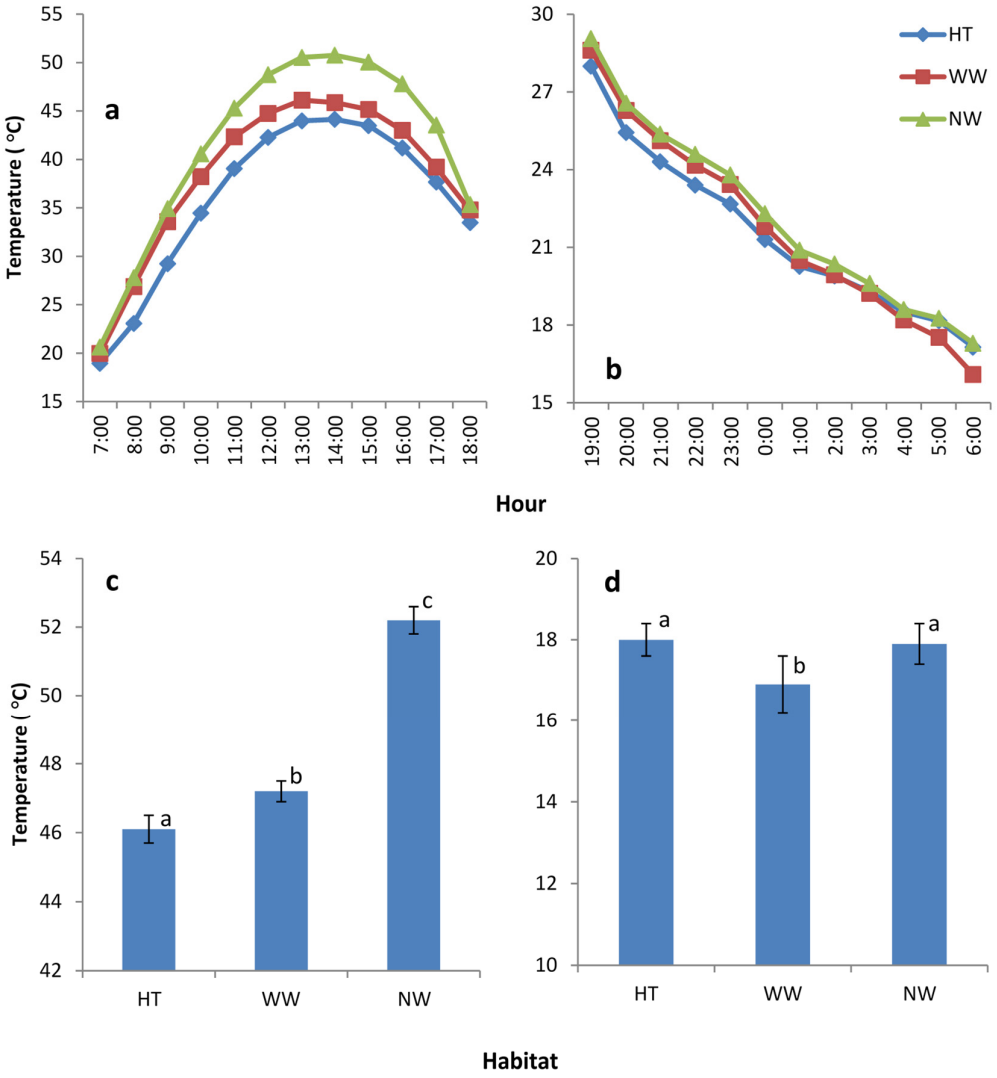

Fig. 4. Average distribution of daily temperatures (a, b) and average maximum (c) and minimum temperatures (d) as measured during August 16th and August 31st, 2014. Bars represent one SE.

In comparison to low wind velocities of 1.5–2.0 s^{-1} that characterized the nights, relatively high velocities of 5–7 m s^{-1} characterized the afternoons (Kidron et al., 2000), during which high differences were monitored between wind-exposed to wind-sheltered habitats. This was evident in the wind velocities shown in Figure 1, which were further supported by additional measurements (using portable anemometers) which exhibited the same pattern with HT > WW > NW (not shown). This was also evident by the wind velocities measured at the wind-exposed west-facing slope in comparison to the wind-sheltered east-facing slope. While wind velocities of 3–4 m s^{-1} characterized the west-facing midslope during the afternoon and early evening, the corresponding values at the east-facing midslope were 1.5–2.0 s^{-1} (Kidron et al., 2016). The substantially high NRW at the west-facing slope despite the similar input of radiation at both slopes (Geiger, 1966), was explained by the differences in the wind regime, which subsequently also resulted in the higher biomass of the lithic microorganisms at the west-facing slope (Kidron et al., 2016).

With vapor condensation taking place once $T_s \leq T_d$, it is widely assumed that habitats which exhibit lower minimum temperatures (and therefore having higher probability of reaching T_d) may also benefit from higher amounts of dew (Andrade, 2003; Matimati et al., 2013; Wang et al., 2014). This assumption is supported by the inverse relationship between early morning temperatures and dew amount (Kidron and Temina, 2017). However, the relationship may be more complex. Thus for instance, lower minimum temperatures were recorded at WW during the late night hours and dawn and nevertheless, NRW at WW was lower than at HT. Apparently, the higher amounts of NRW at HT do not necessarily reflect only the most lower temperatures that were measured during the late night hours but rather reflect also the temperatures that characterize this habitat during the early and midnight hours. Subsequently, the minimum temperature (as measured at or close to dawn) may not always predict the amounts of NRW. The current findings point to the cumulative effect of all nocturnal temperatures that may affect NRW, i.e., the length of time during nighttime, during which adequate conditions conducive to vapor condensation take place. Further measurements are however required to assess this preliminary conclusion.

During the current research period, the classical model was registered only during three mornings. At least for one of these mornings (2.11.2012), it may have been a result of a high-velocity wind

that began at midnight and evaporated most of the dew that was already formed. It principally affected the wind exposed station of HT. Yet, during all other mornings, substantially higher amounts of dew were recorded at HT, in disagreement with the classical model.

As far as the NRW is concerned, the overwhelming effect of the late afternoon winds principally affected HT, i.e., the habitat which is mostly exposed to the sea breeze winds. This conclusion is supported by periodical dew measurements that took place during the winter of 2013 at HT and NW during which higher dew values were recorded at NW, in agreement with the classical model. Nevertheless, given the fact that dew during the wet season may also include distillation, i.e., vapor that originates from the wet ground (following rain) and condenses on cobbles or leaves (Kidron et al., 2022; Monteith, 1957), the moisture values cannot be solely regarded as dewfall. Therefore, dew values during the winter should be cautiously examined. The negative relations between nocturnal temperatures and NRW (Kidron and Kronenfeld, 2022) facilitate indeed an assessment of the spatial distribution of NRW.

A comparison of temperatures measured on cobbles during the winter (January 1st and 21st, 2013) at HT and NW is shown in Figure 5a. Lower nocturnal temperatures characterize NW, attributed to the overwhelming effect of the katabatic winds once the sea-breeze winds did not take place. The central role attributed to the afternoon winds in dew formation is supported once a comparison of the wind regime during the fall and the winter takes place.

Figure 5b shows the hourly relative velocities of winds during 21 days during the fall (October 11th to 31st, 2014) and winter (January 1st to January 21st, 2013) as recorded by the adjacent (Sede Boqer) meteorological station. A sharp increase in the relative wind velocity (i.e., the velocity above the background velocity) characterizes the fall winds during the late afternoon, i.e., just before the onset of dew formation. As can be also seen in the insets of Figure 5b, while multidirectional winds characterize the winter, predominating northwestern winds (which carry vapor from the Mediterranean) characterize the fall. Thus, by not playing a central role in cooling the cobbles during the early evening (prior to vapor condensation) and by not providing the necessary vapor from the Mediterranean Sea, dew distribution during the winter is substantially less affected by the regional sea breeze winds, while being more affected by the local katabatic winds. Expectedly, dewfall during the winter may be indeed lower (Evenari et al., 1971), a phenomenon that may be largely attributed to the absence of the sea breeze, and the subsequent lower vapor content in the lower atmosphere.

Our data suggest that dew formation in the Negev is closely linked to the role played by winds, whether the local (katabatic) or the regional (sea breeze) winds. The cooling effect of the regional winds during the late summer and fall masks that of the local katabatic winds. Subsequently, lower nocturnal temperatures characterize HT and WW during the late summer and fall in comparison to NW, which may explain in turn the higher NRW at HT, in disagreement with the classical model. However, once the cooling effect of the sea breeze is no longer dominant (during winter), dew distribution is principally determined by the local (katabatic) winds, complying with the classical model.

Unlike NW which was only slightly affected by the sea breeze, WW was more affected, but yet, except for the late nighttime hours, it exhibited higher minimum temperatures in comparison to HT. Since dew accumulation is time-dependent

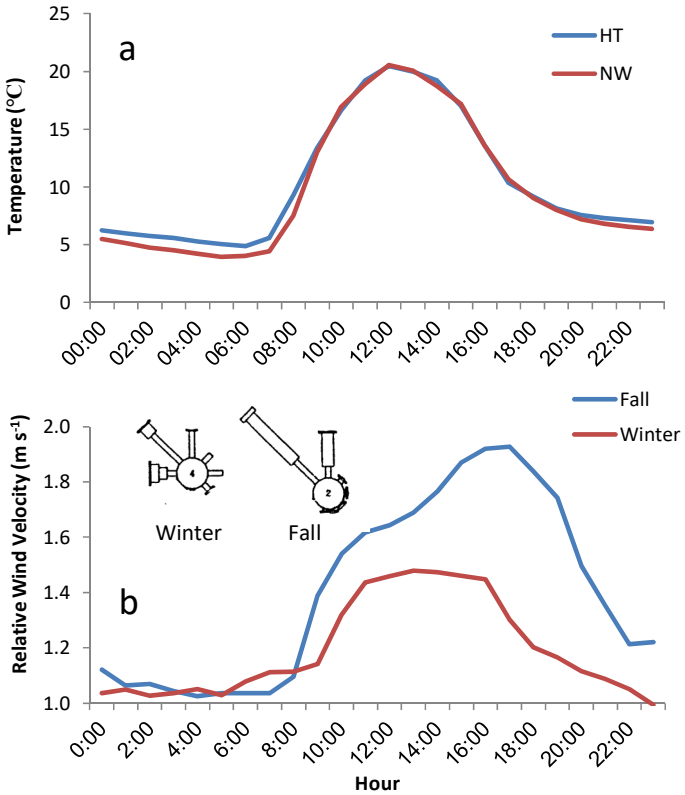

Fig. 5. Average daily temperatures during the winter period (January 1st to January 21st, 2013) (a), and relative wind velocity (i.e., the velocity above the background velocity) during 21 days during the fall (October 11th to 31st, 2014) and winter (January 1st to January 21st, 2013) (b). The wind roses in the inset of b represent the wind regimes during the fall and winter (after Bitan and Rubin, 1991).

(the time duration during which $T_s \leq T_d$), the nighttime distribution of temperatures (rather than only the single value that represent the minimum temperature- commonly at or near dawn) should be considered once the relative amount of NRW of different habitats is sought.

As far as the water regime for lithobionts and plants during the dewy (but rainless) season is concerned, WW may provide higher amounts of dew than NW. Moreover, with distillation playing also an important source of water (Kappen et al., 1979), the effect of distillation should be also explored, especially in WW, where relatively thick alluvial soils may retain moisture (and provide near surface vapor) for longer duration.

5 CONCLUSIONS

Previous measurements of the spatial distribution of dew exhibited a unique pattern that did not comply with the classical model which predicts high dew accumulation at the wadi beds. Rather, dew measurements that took place at the wadi bed yielded ~0.5 the amount received at the hilltop. Hypothesizing that this phenomenon is particularly limited to wind-sheltered narrow wadis and that the cooling effect of the afternoon sea-breeze winds may have an overwhelming effect over the katabatic winds, periodic measurements of dew and temperature were conducted at the hilltop, at a wide wadi bed and at the narrow wadi. Our findings only partially supported our hypothesis. Albeit the effect of the local (katabatic) winds, both wadis were found to exhibit lower amounts of dew than the hilltop during the fall dewy period, explained by the overwhelming effect of the regional (see breeze) winds. The sea breeze winds were responsible for long hours of low temperatures at the hilltop, compensating for the cool air that descends the slope during the night to accumulate at the wadi bed (katabatic winds). Our findings were indirectly supported by the lower temperatures that were recorded at the narrow wadi during the winter, during which the sea breeze does not commonly take place and the katabatic winds result in low nocturnal temperatures. The findings highlight the variable effects of the regional (sea breeze) and local (katabatic) winds on dew formation, pointing to the possibility that regions subjected to sea breeze may not comply with the classical model of dew distribution.

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REFERENCES

Andrade, J.L., 2003. Dew deposition on epiphytic bromeliad leaves: An important event in the Mexican tropical dry deciduous forest. Journal of Tropical Ecology, 19, 479–488. DOI: 10.1017/S0266467403003535

Ashbel, D., 1949. Frequency and distribution of dew in Palestine. Geographical Review, 39, 291–297. DOI: 10.2307/211050

Aylor, D.E., 1990. The role of intermittent wind in the dispersal of fungal pathogens. Annual Review of Phytopathology, 28, 73–92. DOI: 10.1146/annurev.py.28.090190.000445

Beysens, D., 1995. The formation of dew. Atmos. Res., 39, 215–237. DOI: 10.1016/0169-8095(95)00015-J

Beysens, D., 2018. Dew Water. River Publishers, Gistrup, Denmark. 305 p.

Beysens, D., Pruvost, V., Pruvost, B., 2016. Dew observed on cars as proxy for quantitative measurements. Journal of Arid Environments, 135, 90–95. DOI: 10.1016/j.jaridenv.2016.08.014

Bitan, A., Rubin, S., 1991. Climatic Atlas of Israel for Physical and Environmental Planning and Design. Ramot Publishing, Tel Aviv University.

Broza, M., 1979. Dew, fog and hygroscopic food as a source of water for desert arthropods. Journal of Arid Environments, 2, 43–49. DOI: 10.1016/S0140-1963(18)31703-8

Clus, O., Ouazzani, J., Muselli, M., Nikolayev, V.S., Sharan, G., Beysens, D., 2009. Comparison of various radiation-cooled dew condensers using computational fluid dynamics. Desalination, 249, 707–712. DOI: 10.1016/j.desal.2009.01.033

Duvdevani, S., 1957. Dew research for arid agriculture. Discovery, 18, 330–334.

Evenari, M., 1981. Ecology of the Negev Desert, a critical review of our knowledge. In: Shuval, H. (Ed.): Developments in Arid Zone Ecology and Environmental Quality. Balaban ISS, Philadelphia, Pa, pp. 1–33.

Evenari, M., Shanan, L., Tadmor, N., 1971. The Negev, The Challenge of a Desert. Harvard Univ. Press, Cambridge, Massachusetts, 345 p.

FAO, 1977. World Map of Desertification. Food and Agricultural Organization (FAO), Rome.

Geiger, R., 1966. The Climate near the Ground. Harvard Univ. Press, Cambridge, Mass. 482 p.

Hill, A., Dawson, T.E., Shelef, O., Rachmilevitch. S., 2015. The role of dew in Negev Desert plants. Oecologia, 178, 317–327. DOI: 10.1007/s00442-015-3287-5

Iserloh, T., Fister, W., Marzen, M., Seeger, M., Kuhn, N.J., Ries, J.B., 2013. The role of wind-driven rain for soil erosion- An experimental approach. Zeitschrift fur Geomorphologie, 57, 193–201.

Jia, R.L., Li, X.R., Liu, L.C., Gao, Y.H., Li, X.J., 2008. Responses of biological soil crusts to sand burial in revegetated area of the Tengger Desert, Northern China. Soil Biology and Biochemistry, 40, 2827–2834. DOI: 10.1016/j.soilbio.2008.07.029

Kappen, L., Lange, O.L., Schulze, E.-D., Evenari, M., Buschbom, V., 1979. Ecophysiological investigations on lichens of the Negev Desert, IV: Annual course of the photosynthetic production of *Ramalina maciformis* (Del.) Bory. Flora, 168, 85–105. DOI: 10.1016/S0367-2530-(17)31899-6

Kidron, G.J., 2000a. Analysis of dew precipitation in three habitats within a small arid drainage basin, Negev Highlands, Israel. Atmospheric Research, 55, 257–270. DOI: 10.1016/S0169-8095(00)00063-6

Kidron, G.J., 2000b. Dew moisture regime of endolithic and epilithic lichens inhabiting calcareous cobbles and rock outcrops, Negev Desert, Israel. Flora, 195, 146–153. DOI: 10.1016/S0367-2530(17)30962-3

Kidron, G.J., Kronenfeld, R., 2022. Lithic cyanobacteria as bioindicators for dewless habitats within a dew desert. Flora, 288, 152027. DOI: 10.1016/j.flora.2022.152027

Kidron, G.J., Starinsky, A., 2012. Chemical composition of dew and rain in an extreme desert (Negev): Cobbles serve as sink for nutrients. Journal of Hydrology, 420–421, 284–291. DOI: 10.1016/j.hydrol.2011.12.014

Kidron, G.J., Temina, M., 2013. The effect of dew and fog on lithic lichens along an altitudinal gradient in the Negev Desert. Geomicrobiology Journal, 30, 281–290. DOI: 10.1080/01490451.2012.672542

Kidron, G.J., Temina, M., 2017. Non-rainfall water input determines lichen and cyanobacteria zonation on limestone bedrock in the Negev Highlands. Flora, 229, 71–79. DOI: 10.1016/j.flora.2017.02.015

Kidron, G.J., Zohar, M., 2010. Spatial evaporation patterns within

a small drainage basin in the Negev Desert. Journal of Hydrology, 380, 376–385. DOI: 10.1016/j.jhydrol.2009.11.012

Kidron, G.J., Yair, A., Danin, A., 2000. Dew variability within a small arid drainage basin in the Negev highlands, Israel. Quarterly Journal of the Royal Meteorological Society, 126, 63-80. DOI: 10.1002/qj.49712656204

Kidron, G.J., Kronenfeld, R., Starinsky, A., 2016. Wind as a cooling agent: Substrate temperatures are responsible for variable lithobiont-induced weathering patterns at the west- and east-facing limestone bedrocks of the Negev. Earth Surface Processes and Landforms, 41, 2078–2084. DOI: 10.1002/esp.3973

Kidron, G.J., Kronenfeld, R., Xiao, B., Starinsky, A., 2022. Wet-dry cycles on sandy and loessial Negev soils: implications for biocrust establishment and growth? Ecohydrology, 15, e2379. DOI: 10.1002/eco.2379

Köppen, W.F., 1936. Das Geographische System der Klimate. Gebrüder Borntraeger, Berlin.

Lange, O.L., Schulze, E.D., Koch, W., 1970. Ecophysiological investigations on lichens of the Negev Desert, III: CO_2 gas exchange and water metabolism of crustose and foliose lichens in their natural habitat during the summer dry period. Flora, 159, 525–538. DOI: 10.1016/S0367-2530(17)31062-9

Lee, J.A., 1987. A field experiment on the role of small scale wind gustiness in aeolian sand transport. Earth Surface Processes and Landforms, 12, 331–335. DOI: 10.1002/esp.3290120311

Lloyd, M.G., 1961. The contribution of dew to the summer water budget of Northern Idaho. Bulletin of the American Meteorological Society, 42, 572–580. DOI: 10.1175/1520-0477-42.8.572

Matimati, I., Mausil, C.F., Raitt, L., February, E., 2013. Non-rainfall moisture interception by dwarf succulents and their relative abundance in an inland arid South African ecosystem. Ecohydrology, 6, 818–825. DOI: 10.1002/eco.1304

Monteith, J.L., 1957. Dew. Quarterly Journal of the Royal Meteorological Society, 83, 322–341. DOI: 10.1002/gj.49708335706

Muselli, M., Beysens, D., Mileta, M., Milimouk, I., 2009. Dew and rainwater collection in the Dalmatian Coast, Croatia. Atmospheric Research, 92, 455–463. DOI: 10.1016/j.atmosres.2009.01.004

Oke, T.R., 1978. Boundary Layer Climates. John Wiley and Sons, New York, 372 p.

Riksen, M.J.P.M., Goossens, D., 2007. The role of wind and splash erodsion in inland drift-sand areas in the Netherlands. Geomorphology, 88, 179–192. DOI: 10.1016/j.geomorph.2006.11.002

Rodriguez-Navarro, C., Doehne, E., Sebastian, E., 1999. Origins of honeycomb: The role of salts and wind. GSA Bulletin, 111, 1250–1255. DOI: 10.1130/0016-7606(1999)111<1250:OOHWTR>2.3.co;2

Rosenan, N., Gilad, M., 1985. Atlas of Israel. Meteorological Data, Sheet IV/2. Carta, Jerusalem (Israel).

Spinoni, J., Vogt, J., Naumann, G., Carrao, H., Brbosa, P., 2015. Towards identifying areas at climatological risk of desertification using the Köppen-Geiger classification and FAO aridity index. International Journal of Climatology, 35, 2210–2222. DOI: 10.1002/joc.4124

Tanaka, H., Shibata, M., Nakashizuka, T., 1998. Evaluation of the role of wind dispersal in tree population dynamics by using a mechanistic approach. Journal of Sustainable Forestry, 6, 155–174. DOI:10.1300/j091v06n01_10

Takenaka, N., Soda, H., Sato, K., Terada, H., Suzue, T., Bandow, H., Maeda, Y., 2003. Difference in amounts and composition of dew from different types of dew collectors. Water Air and Soil Pollution, 147, 51–60. DOI:10.1023/A: 1024573405792

Temina, M., Kidron, G.J., 2015. The effect of dew on flint and limestone lichen communities in the Negev Desert. Flora, 213, 77–84. DOI: 10.1016/j.flora.2015.04.005

Wang, X.P., Pan, Y.X., Hu, R., Zhang, Y.F., Zhang, H., 2014. Condensation of water vapour on moss-dominated biological soil crust, NW China. Journal of Earth System Sciences, 123, 297–305. DOI: 10.1007/S12040-013-0397-5

Zangvil, A., 1996. Six years of dew observation in the Negev Desert, Israel. Journal of Arid Environments, 32, 361–372. DOI: 10.1006/JARE.1996.0030

Zhuang, Y., Zhao, W., 2014. Dew variability in three habitats of a sand dune transect in a desert oasis ecotone, Northwestern China. Hydrological Processes, 28, 1399–1408. DOI: 10.1002/hyp.9675

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